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Managing food security through food waste and loss: Small data to big data

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ABSTRACT

This paper provides a management perspective of organisational factors that contributes to the reduction of food waste through the application of design science principles to explore causal relationships between food distribution (organisational) and consumption (societal) factors. Qualitative data were collected with an organisational perspective from commercial food consumers along with large-scale food importers, distributors, and retailers. Cause-effect models are built and "what-if" simulations are conducted through the development and application of a Fuzzy Cognitive Map (FCM) approaches to elucidate dynamic interrelationships. The simulation models developed provide a practical insight into existing and emergent food losses scenarios, suggesting the need for big data sets to allow for generalizable findings to be extrapolated from a more detailed quantitative exercise. This research offers itself as evidence to support policy makers in the development of policies that facilitate interventions to reduce food losses. It also contributes to the literature through sustaining, impacting and potentially improving levels of food security, underpinned by empirically constructed policy models that identify potential behavioural changes. It is the extension of these simulation models set against a backdrop of a proposed big data framework for food security, where this study sets avenues for future research for others to design and construct big data research in food supply chains. This research has therefore sought to provide policymakers with a means to evaluate new and existing policies, whilst also offering a practical basis through which food chains can be made more resilient through the consideration of management practices and policy decisions.

1. Introduction

The terms food loss and food waste are often used interchangeably and ground in legal jurisdictions but they are quite different in terms of origin and scope. According to Parfitt et al. (Parfitt et al., 2010), food 'waste' is most readily defined at the retail and consumer stages, where outputs of the agricultural system are self-evidently 'food' for human consumption.

However, food 'loss' refers to the decrease in food quantity or quality, which makes it unfit for human consumption; occurring throughout the supply chain; from harvest through to processing and distribution. This wasted food, which is still potentially fit for human consumption, could potentially feed those in need and thereby contribute to enhancing food security. By reducing food losses and waste, more food could be made available for consumption without the need for more farm output (Babar and Mirgani, 2014). If only one-fourth of the food wasted could be saved, it would be sufficient to feed all currently undernourished people (Basher et al., 2013).

Although there are numerous definitions as to what constitutes food waste in different legal jurisdictions (often grounded around environmental, hygiene, nutrition and food safety controls), there remains a basic premise that food is lost and wasted throughout the different stages of the food supply chain. These stages range from the agricultural production, processing, distribution, retail,

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consumption and ultimately disposal (before potential recycling) although it is recognised that there may be up to eleven stages of food supply chain waste (Chen et al., 2009).

Food waste itself has multiple facets that encompass, technical, organisational, managerial and societal impacts. It promotes an ineffective use and distribution of resource that signals inefficiencies throughout supply chains with significant embedded energy loss that represents an accumulation of energy and effort to no positive effect. Traditional views of waste orientate around what one leaves behind after eating, or dispose as unused yet; waste is a much broader domain that has multiple dimensions, each with its own commercial, societal and environmental impact (such as for example, the fact that approximately 1.4 billion hectares of land equates to the total sum of all uneaten food, which accounts for 30% of the Earth's agricultural land mass). Indeed, it is estimated that in the United States, energy embedded in food waste represents approximately 2% of total energy consumption (Engström and Carlsson-Kanyama, June 2004).

Irani and Sharif (Irani and Sharif, 2016) presented a taxonomy that reflects *how* the phases associated with food chain waste can be classified. Through the better understanding of such classification, appropriate strategies can be constructed and implemented from producer to consumer; aligned to organisational and technological strategies. A multifaceted policy approach should target both commercial and residential behaviours. Commercial behaviours as they are the major players in the amount of food produced and distributed and residential behaviours as consumers' choices are among the major drivers of food waste.

Improved operational efficiencies and engineering management enhancements during agriculture, processing, distribution or management practices will go some way to improving efficiencies. Yet, without significant innovations, food waste is set to become an increasingly pressing societal problem that questions the equitable distribution of *what* we eat, *how* and *where* it is produced along with the reasons of *why* waste occurs. Therefore, a new approach to exploring those organisational factors that contribute to managing food security through waste reduction is needed. This is especially the case when regions or countries are faced with importing large quantities of food – such as in the case of Qatar that imports 97% of its food requirement (Papargyropoulou et al., August 2014) – but where there is a fundamental need to increase self-sufficiency within the next decade by 2025 (Stefan et al., April 2013, Williams et al., March 2012, Secondi et al., 2015). In addressing such challenges, the authors seek to use an outcome-based research methodology, which offers guidelines for the evaluation and iteration of complex organisational challenges (beyond those which are either based upon human, intellectual or relational capital (Quested et al., Oct. 2013)), using the Qatari context as the focal point of a simulation scenario as part of funded research that explores the reduction of food waste.

In addressing such challenges, the authors seek to use an outcome-based research methodology, which offers guidelines for the evaluation and iteration of complex organisational challenges (beyond those which are either based upon human, intellectual or relational capital (Quested et al., Oct. 2013)). This research is based on the Qatari context using it as the focal point of a simulation scenario as part of funded research that explores the reduction of food waste. The contribution in this paper lies in the exploration and suggestion of how causal interrelationships interact and the dynamic simulation of these factors using Fuzzy Cognitive Maps (FCM) via a design science approach that acts as the conceptual basis of this research. The use of these simulation models set against the backdrop of a proposed big data framework for food security, is where this research sets a direction of travel for others to design and construct big data research in the context of food supply chain. Such an approach has the impact to potentially influence and engage policymakers in food waste management through engineering the generation of causal outputs produced through simulation that can impact policy. Therefore, this approach is considered appropriate and timely given the pressures to create and sustain robust food supply chains through appropriate policy development, implementation and enforcement.

2. Literature review: food waste management behaviours

Acquiring sufficient and recent data on food losses at the consumption stage remains a perennial challenge for researchers, although some evidence is available such as via social settings. For example, a study conducted in two school kitchens (850–950 portions / day) and two restaurant kitchens (250 - 600 portions / day) identified that plate waste comprised the highest amount of food waste, followed by storage and preparation losses and serving losses (Thyberg and Tonjes, Jan. 2016, Halloran et al., Dec. 2014).

Other factors contributing to food waste included inventory control (where internal "sell-by dates" were reached), non-compliance of the packaging with market requirements, damages to packaging and product returns. Losses and waste in the food supply chain are inevitable; however, not irreducible. In one example, researchers worked with multiple stakeholders from the Department for Environment, Food and Rural Affairs (DEFRA) in the UK, the Waste and Resource Action Program (WRAP), Fareshare, Brook Lyndhurst, the Sustainable Restaurant Association (SRA), and SKM Enviros (Katajajuuri et al., June 2014). The study conclusion was that a resolution to the food waste situation lies within adopting a sustainable production and consumption approach throughout the global food supply chain.

Building on the Theory of Planned Behaviour, a survey of 244 respondents identified the following factors that lead to food waste: *planning, shopping routine, moral attitudes, lack of concern, subjective norms*, and *perceived behavioural control* (Fehr et al., June 2002). The conclusion of their research was that intention to not waste food did not have a significant impact on the reported food waste and that planning and shopping routines were identified with the most significant variance in the amount of food waste produced. Whilst planning supported the reduction of food waste, shopping routines increased the levels of food waste. Perceived behavioural control over household food consumption appear to positively influence planning routines and negatively influence shopping routines, thus being the most important influence in explaining reported food waste.

Surveys of families to understand the causes of food waste have elicited packaging as a key aspect of the problem. For example, around 25% of the food waste is related to packaging: either too big for the consumer, or too difficult to empty (Warshawsky, Dec. 2015). The main conclusion in the latter research was that consumer awareness about the food waste was key to reducing it. In another survey conducted with citizens in the EU-27 (Irani et al., 2015), several additional factors were identified that encouraged people to reduce their food waste: *attitudes, values, motivation, habits, perceived social norm, knowledge and skills related to behaviour, facilities and resources.* Although factors were related, no direct cause-effect relationship among them could be concluded.

Cultural, governmental, demographic, technological, economic, and industrial factors affect the food waste in the supply chain and in the households (Sharif et al., 2012), as do socio-demographic, cultural, political and economic drivers (Kok, 2009). The research suggests that policies to reduce and prevent food waste can change people's behaviour, both collectively and individually thus, suggesting the need through which new policies can be developed and evaluated for human and organizational impact. Main strategies exist to tackle food waste, including sharing information and knowledge across stakeholders, broadening legislation, focusing on

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packaging as part of the solution, and thinking circular instead of linear; sustainable solutions for food waste reduction should consider multi-stakeholder collaboration, especially public-private partnerships at the global level (O'Keefe, 2014).

The amount of produced food waste depends on the stakeholder, and varied significantly across the food chain; from the agriculture industry, food production and distribution, wholesale and retail, restaurants and households. The resources (land, fertilizers, fuel, materials, transportation, water and energy) used to cultivate, produce, store and distribute food are wasted when the food is not used and then discarded. These resources have significant greenhouse gas emissions and environmental impacts (e.g. water eutrophication, methane from landfills). Therefore, the potential for impact when reducing food waste by the food service sector and consumers is significant (Peffers et al., 2007) but this potential can only be realized through cooperation that spreads across the stakeholder range and may require government intervention and support in the form of robust policies. Therefore, some means through which policies changes can be evaluated through simulation has the potential for significant impact to stakeholders throughout the food supply chain.

Given that the evaluations of food waste policies are scarce, it is not clear which combination(s) of intervention (and where in the supply chain) to prevent food waste is most effective (Kok, 2009). From an ecological point of view, food waste going to landfill creates undesirable consequences that range from nutritional loss to a waste of embodied energy and methane production. As a result, policymakers have a responsibility to not only prevent waste but also manage the disposal and impact of the food waste (22). The making of policy that meets societal needs can only be achieved through a better understanding of the food waste life cycle, as it evolves from production and distribution to consumption and disposal.

There are multiple policies in statutes to tackle the food waste. However, the outcomes of these policies are not always positive. For example, the decentralization, privatization and devolution of food waste governance to local institutions may not effectively reduce food waste (Hevner et al., 2004). Food waste policies are influenced by non-state actors at community, household or individual levels, resulting in uneven food waste, lack of accountability and inadequate data to understand the criticality of food waste to food security. This research is not seeking to make a theoretical contribution but is motivated by:

- There is a need for all stakeholders in the food chain (providers and consumers) to better understand their role in contributing towards the enhancement of food security.
- Policymakers do not have the means to ex-post evaluate the human and the organizational implications and the impact of their interventions to reduce food waste within the broader food security landscape.

In line with the above observations, the authors seek to answer the following broad research questions when grounded within a robust methodology that adopts a design science approach:

1. What are the roles of food chain stakeholders in achieving food security and how can the interrelations between their roles be established?
2. How can policymakers ex-post evaluate the impact of their policy interventions to reduce food waste and improve food security?

The challenges arising from high degrees of complexity around food waste necessitates input from all stakeholders to 'unpack' the food waste challenge from both an academic and practitioner perspective, so that future policies could be informed or developed accordingly.

3. Big date: emerging potential

Big data analytics have received attention firstly in computer science and information systems disciplines (Agarwal and Dhar, 2014, Demirkan and Delen, 2013). In the Operations Research (OR) discipline, big data has been recently gained importance and studies report the impact of big data analytics on operations management and operations research. Traditional data analytics techniques are still used to analyse large volume of data. Fang et al. (Fang et al., 2016), for example, applied random forecast regression model to predict the profitability of customers using big data obtained from insurance companies in China. However, as the volume of data dramatically increases the practicality of using traditional techniques becomes an issue. Heuristic methods finding practical sub-optimal solutions within reasonable time constraints become more useful. For example, Nikolopoulos and Petropoulo (Nikolopoulos and Petropoulos, 2017) report that there are cases that sub-optimized forecasting models in terms of within-sample fitting do not produce worse forecasting performance over time in the presence of big data. Therefore, considering computing cost to obtain optimal forecasting models and parameter sets, sometimes sub-optimal model can be of benefit for managers. Kaur and Singh (Kaur and Singh, 2017) also apply a heuristic modelling approach based on binary variable relaxation to solve an optimization problem for minimizing procurement cost and greenhouse gas (GhG) emissions from procurement and logistics. Their computational results show that the heuristic technique can find near optimal solutions (with up to 5% error) within a minute.

While such studies are focused on the use of large volume of data for finding optimal solutions or prediction, there is limited number of studies that focus on the use of big data for qualitative decision models. Choi et al. (Choi et al., 2017) and Tan et al. (Tan et al., 2015) are few examples of such studies. Choi et al. (Choi et al., 2017) use small data for supporting qualitative decision modelling and simulation. They propose a novel way to integrate open small data available on the Internet with fuzzy cognitive map that is mainly used for qualitative group decision-making. Tan et al. (Tan et al., 2015) integrate big data analytics with a deduction graph (a qualitative causal decision model). In their approach, a data mining technique is used to extract information for nodes of a deduction graph from qualitative big data. Other examples of Big Data applications exist in HR (Shah et al., 2017) and, with Sivarajah et al. (Sivarajah et al., 2017) providing a critical analysis of big data challenges and analytical methods.

4. Research methodology

The authors propose an approach that will support policy makers in evaluating their policy options to enhance food security through reducing waste within the food chain. To explore and identify the interrelationships between organisational factors contributing to the management of food security, the researchers developed a research design to capture aspects of food distribution and consumption that may impact upon the generation of food waste. Methodologically, given the nature of participant interaction, engagement and feedback, the data collection process formed part of an empirical approach that was analyzed in an interpretive sense, to construct a positivist model of food waste factors using the Fuzzy Cognitive Map technique (Kosko, 1986, Sharif and Irani, 2006, Mingers and Rosenhead, 2004).

This design of the research approach attempted to bring together both consumer and distributor (individual and organisational) views of the problem. As such, the research has adopted the elements of a design science approach as described by Rosenhead et al. (Rosenhead, 1996, Thunhurst and Barker, 1999): namely problem identification and motivation, design and development, testing and demonstration and evaluation. The socially constructed nature of these factors involved in food security necessitates that the methodology and underpinning design is aligned to the context and the participants (Friend, 2001, Georgiou, 2008).

The ontology of the design science approach used in this research is rooted in multiple *realities* (organisations generating / contributing to the food supply, organisations and individuals generating the food demand); the epistemological basis is constrained through iterative circumscription (a workshop data collection process in a given geographical context); and there is a mixed set of research methods employed (qualitative participant contribution that is then quantified to allow the modelling of interrelationships between factors affecting the food waste within a given context for situational analysis). Further, problem identification and motivation was achieved through contextualising the research domain in terms of the food security challenge(s) within the chosen geographically location of Qatar; where the primary data collection for this research was carried out. In addition, the *users* were identified prior to the research in terms of being appropriate research participants relating to the *production, supply* and *consumption* of food.

An important element of the design science approach, the artefact, embodies the relevant organisational problem (food waste) and knowledge (stakeholder perspectives on food security). As a result, the artefact used was a causal cognitive map (through Fuzzy Cognitive Mapping) of the interrelationships involved in an organisational frame of thinking in relation to food waste. In addition, design science requires that the artefact is designed and developed so that it is relevant to the context of the problem domain (Qatar). It is important to note that in the present study, the researchers have not sought to build theory but rather to construct artefacts through FCMs that show complex interrelationships that contribute towards food waste. Such FCMs can then be manipulated through simulation to demonstrate *what-if* scenarios to support food security through waste reduction within the food production, distribution and consumption. The methodology adhered to the guidelines and ethical procedures of the lead partner institution (Georgetown University) and aligned to the ethical approval principles from individual institutions of all researchers. Fig. 1 highlights the overall research design and approach of the research reported.

The research design involved the following steps with reference to the design science considerations identified earlier:

1. Identification of problem and choice of participants:
- Noting this methodological stance, the investigative team approached an initial list of 330 stakeholders that were sourced from various online directories, which included companies working in distribution and logistics as well as food importers, food exporters, wholesalers, manufacturers, custom clearance services, catering services etc in Qatar.
- In addition, through the project team member's personal network; additional consumers, government officials, hotels, restaurants, Non-Governmental Organisation (NGOs), members were identified and approached to participate in this study. In total over 400 people and companies were contacted through, among others, telephone and email. The formal invitation to attend one or both workshops was sent to 135 potential participants. Overall, a total of 34 participants confirmed their attendance to attend both workshops, with a total of 10 participants for the first workshop (on food supply) and 24 participants for the second workshop (on food consumption). Members were sent briefing packs in advance and confirmed receipt.
- The two research workshops were held in the Executive Program Suite in the School of Foreign Service (SFS) at Georgetown University, in Doha which is in the State of Qatar. They were led and facilitated by senior research staff that had experience of running workshops of this nature; with the intention to extrapolate meaningful qualitative data that would provide an insight to the contributing factors to food waste.
- The basis of the two sessions was that of a facilitated participant workshop, where participants were to be asked to *identify, prioritise, categorise* and *relate* the factors they perceived as being relevant to food waste and food security in Qatar. Participants were informed ahead of time of their required input, informed consent and anonymity being part of the ethical procedures used for this primary data collection, with ethical approval. This was achieved by providing each participant with a workshop schedule and an informed consent form.

2. Prioritisation of factors.
- Specifically, the workshop commenced with a presentation on food security issues in terms of the global and Qatar-specific challenges – this provided the broad regional context to the workshop. The presentation was followed by specific instructions on how the participants would need to engage in groups to address and provide responses to specific food waste / security questions as follows:
- Workshop Question 1: How can food distribution and supply be sustained in Qatar whilst reducing food waste? (Participants on the supply side).
- Workshop Question 2: What changes in food consumption behaviour might lead to a reduction in food waste? (Participants on the demand side).
- Participants were assigned into equally sized groups for each workshop, whilst also carefully noting to maintain diversity of expertise in each group. Hence for workshop one relating to the supply-side, this equated to five groups of two people each; and for workshop two relating to the consumer-side, this equated to six groups of four people each. Group members were then asked to form into their groups and were provided with Sticky notes, flip-chart markers and a flip chart to facilitate their discussion of the causes of food waste within their perspectives (supply vs. demand).
- Specifically, the workshop preceded a presentation given by a lead investigator, where broader context on food security in terms of the global and Qatar-specific challenges were presented – this ensured broad regional context to the workshop. This was followed by specific instructions on how the participants would need to engage in groups to address and provide responses to a specific food waste / security question(s), in terms of the following key research questions:
- RQ1: How can food distribution be sustained in Qatar whilst reducing food waste? (Production and Supplier participants).
- RQ2: What changes in food consumption behaviour might lead to a reduction in food waste? (Consumer participants).
- Based upon these questions, each group were then asked to discuss and identify the top 20 factors that affect or are related to the food waste. There was no scientific reason to choose 20, other than orientating findings around a number that was considered large enough to produce meaningful findings yet not too large as to then need statistical justification. This was to be achieved by writing one factor per sticky note and attaching it to the flip chart paper provided.
- Following the elicitation of factors, each group was then asked to prioritise and rank a maximum of 10 sticky note items from the above list of 20 factors. In doing, writing the prioritised number in the top right-hand corner in red pen.

3. Categorisation of factors
- During and following each of the above steps, the workshop team facilitated the discussions and helped each group to detail their responses and photographed each stage of group output (i.e. photographs of the Post-It notes on the flip charts). Partici-

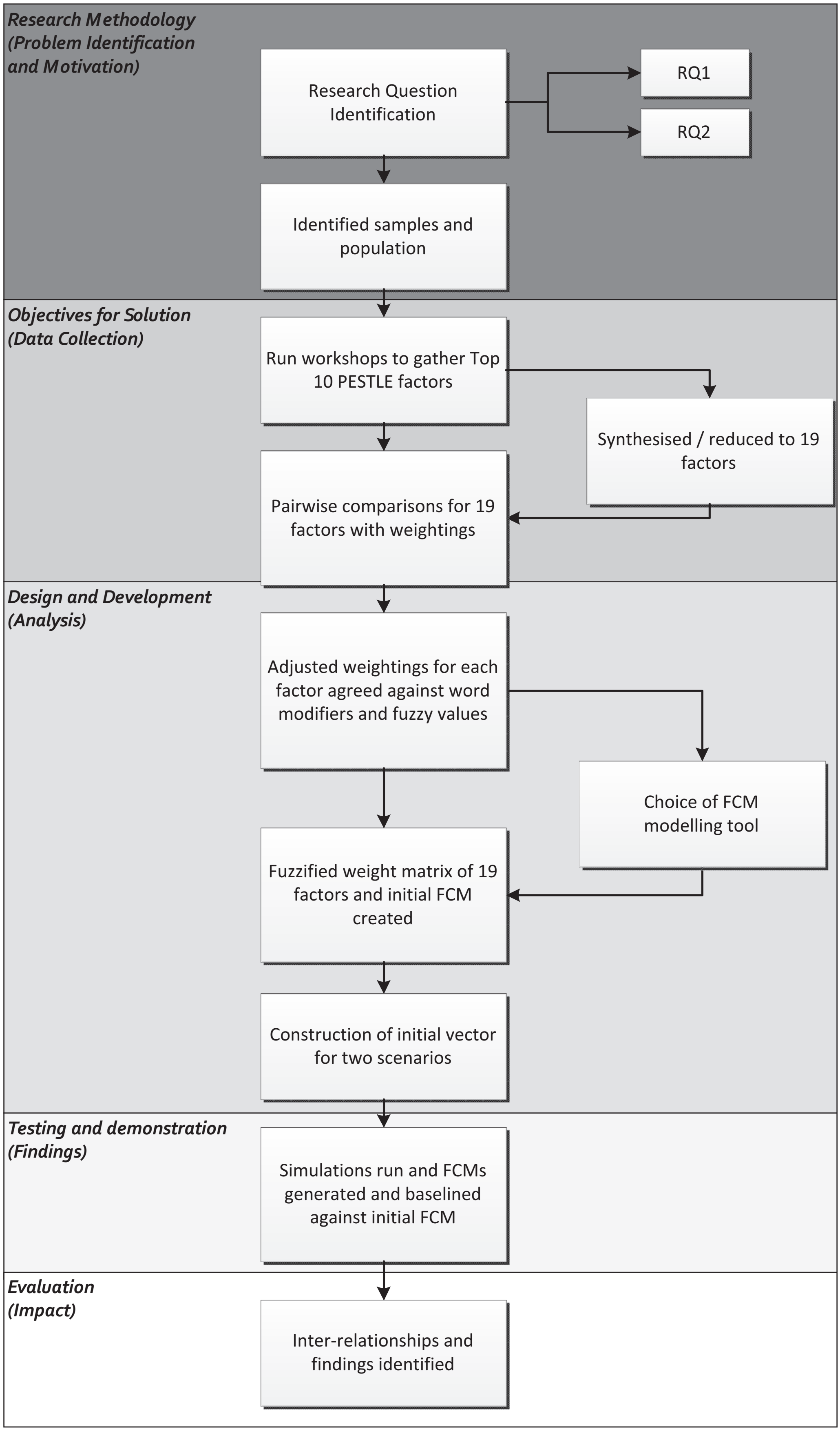

Fig. 1. Research design based upon design science principles.

pant anonymity was ensured and the captured data were stored on a secure online shared drive for later analysis.

- A strategic management tool was used in the workshops to give structure to participants and to frame their thinking. This tool involves the identification of Political, Economic, Social, Technological, Legal and Environmental (PESTLE) factors. For each supply-perspective and demand-perspective prioritised lists, a pairwise comparison was carried out, to elicit the cause and effect relationships (positive or negative) between the factors identified. Each group was then requested to place the identified top 10 sticky note items onto a grid of factors using the PESTLE strategic planning tool:
- Political (e.g. to what extent does the government intervenes in global, national economy).
- Economic (e.g. economic growth factors impact on how businesses operate and make decisions).
- Social (e.g. cultural and behavioural aspects and other developments in society).
- Technological (e.g. developments, such as Research and Development (R&D) activities, automation, rate of technological change).
- Legal (e.g. how legislation affects an organisation's operations, its costs, and demand for its products).
- Environmental (e.g. ecological and related aspects, such as weather, climate).
- After assembling the PESTLE factors across each of the groups (as described previously), a consolidated and prioritised list of food waste factors was produced for both perspectives using the thematic grouping.

4. Interrelationships among factors

- After reviewing each of the sticky-It note, factors identified above on the PESTLE grid, each group were then requested to look at pairwise comparisons between each factor, assembling this on a grid of *n* x *n* factors from the steps above. This approach is commonly used in a variety of fields as discussed by Pidd (Pidd, 2003) to study relative importance, preferences, attitudes and social choices as described by Daellenbach (Daellenbach, 1997).
- For each compared pair of factors, each group were then asked to assign a positive causal (+), negative causal (−) or neutral value (0, no cause-effect relationship), by writing the appropriate symbol in the top left-hand corner of each sticky note. By assigning weights, the team would then be able to construct Fuzzy Cognitive Maps (FCMs) that will consider the identified interrelationships simultaneously (Chou et al., 2010). There is no claim of methodological contribution when it comes to the use of FCMs but this scientific approach was considered appropriate when it comes to creating a landscape where causal relationships could be simulated to establish relationships around justified assumptions.

5. Data collection process

Table 1 presents a collated prioritised list from the supply-perspective and demand-perspective workshops listing the responses of individual participant groups to how food production and supply, as well as changes in food consumption behaviour might lead to a reduction in food waste in Qatar (note: Supply-Perspective groups are denoted by SP[*n*] and Demand-Perspective groups are denoted by DP[*n*].[*F*]*m* where *n* is the group number, F is the PESTLE variable and *m* is the priority given by the given workshop participant group).

As can be seen from Table 1, participants from the food supply-perspective identified and prioritised eight *economic*, seven *technical*, five *legal*, four *political and environmental*, and three *social* factors. In contrast, participants from the food demand-perspective identified and prioritised 21 *social*, seven *economic*, six *technical*, five *environmental*, four *legal* and three *political* factors. These results were perhaps not surprising given the expertise. Moreover, starting assumptions of each group were either based around largely operational / technical (and supply) or societal / individual (consumption) contexts. Both sets of prioritised factors do show some concurrent themes that can be broadly grouped into themes around: government legislation; food demand planning and forecasting; the local production of food (less reliance upon external sources and imports); changing food consumption, preparation and buying behaviours/patterns (noting culture, religion and lifestyle elements); food quality governance, control and regulation; education and training for food professionals and those across the food supply chain; and, improvements to the recycling, recovery and reuse of food in general as part of the overall waste cycle.

As a result, the researchers then identified those key factors that arose from this exercise as shown in Table 2. The resulting 20 factors were distilled from 33 unique factors identified by the workshop participants, which were then used as a basis for the subsequent analysis and modelling of interrelationships using the FCM method as detailed in the next section.

6. Analysis through fuzzy cognitive map

Following data collection and capture of the aforementioned prioritised (pairwise) factors for producer and consumer participant groups, the researchers then sought to model the interrelationships between these factors. A range of fuzzy weights were identified that lead to these pairwise factors for each group to be encoded using positive and negative relationships (Bond et al., 2013). By quantifying these values, a matrix (so-called fuzzy weight matrix) was created for each producer and consumer group. This was achieved through interpreting positive and negative causal factors and then applying the fuzzy weights to each.

Subsequently, sets of initial state vectors corresponding to the factors were identified (i.e. starting scenarios). Each fuzzy weight matrix was then input to the FCM modeller along with the initial state vector and the simulation run to provide causal output. These stages are now detailed further below along with assumptions that were used by the researchers.

7. FCM modelling assumptions

The researchers synthesised the workshop data into a more manageable and understandable list for analysing through removing and / or rewording ambiguous or unclear factors before carrying out interrelationship causal mapping. This was done as a precursor to then applying a pairwise comparison from both a food production and consumption perspective to identify inherent interrelationships driving the food waste context in Qatar. This is now described in further detail below.

STEP 1. The researchers sought to avoid bi-directional relationships in the pairwise comparison of producer and consumer factors. The reason for this is that it would lead to limit cycle behaviour (infinite loop) preventing progression of the change propagation at later stages in the simulation process. Hence, the researchers evaluated and chose the stronger causal relationship of the two, per factor, when encountering a bi-directional case. Furthermore, where a factor from the empirical workshop data was ambiguous or poorly defined by the workshop participants, it was discarded. When analysing the interrelationship between each factor (i.e. pairwise relationship), the researchers adopted the perspective of policy makers to view the impact of the interrelationships in a holistic sense (i.e. neither solely from a production, supply or consumption approach but overall from a

Table 1
Example supplier and demand perspectives via PESTLE workshop participants.

Group	Political (P)	Economic (E)	Social (S)	Technological (T)	Legal (L)	Environmental (E)
1	i SP1.P1 Government legislation ii DP1.P6 Increasing awareness of the public	i SP1.E1 Commercially driven food sector ii SP1.E3 Easy, open low cost access to food markets iii SP1.E6 Import controls	i DP1.S3 Right time for shopping ii DP1.S7 Right handling of food iii DP1.S10 Lifestyle changes	i DP1.T5 Reduced quantity of packaging ii SP1.T7 Infrastructure for food logistics iii SP1.T10 Food handling	i SP1.L5 Bureaucracy ii DP1.L9 Greater Co-operation with charity organisations	i SP1.ENV9 Food safety and standards and regulations ii DP1.ENV8 Recycling of fruits to juice
2	i SP2.P1 Focus group to promote best practice	i SP2.E4 Synergy between food and control authorities and retailers ii SP2.E9 Demand planning iii SP2.E10 Encouraging and investing in local food production	i SP2.S1 Education and training for food professionals ii DP2.S6 Knowing your own food needs iii DP2.S9 Food education	i SP2.T2 Statistics on food production and consumption ii SP2.T7 Storage and supply chain standards iii DP2.T10 Better Production forecasting	i SP2.L3 Standardisation of food regulations ii SP2.L6 “Best before” dates iii DP2.L8 Improvements to Customs rules and airport clearance	i SP2.ENV8 Improving food recycling and packaging ii DP2.ENV1 Food safety iii DP2.ENV7 Food quality
3	i SP3.P3 Government strategy ii SP3.P6 Single food authority	i SP3.E1 Pre-planning of food requirements	i SP3.S8 Communication across all stakeholders ii SP3.S10 Investment in local food initiatives iii DP3.S2 Portion control iv DP3.S3 Nutrition facts v DP3.S5 Consideration of culture and religion	i SP3.T9 Training for food handlers ii DP3.T6 Food management systems iii DP3.T7 Equipment, tools and machinery for cooking	i SP3.L4 Development of compliance and control systems ii SP3.L5 Updating food regulations iii DP3.L8 Legislation for food security	i SP3.ENV7 Quality storage facilities ii DP3.ENV10 *Re*-processing of food
4	i DP4.P9 Educating the public about food waste	N/A	i DP4.S1 Changing culture and food habits ii DP4.S4 Health and exercise awareness iii DP4.S10 Food demand needs of the poor	N/A	i DP4.L8 Food safety at home to reduce food waste	i DP4.ENV2 Learning to grow your own fruit and vegetables
5	i DP5.P1 Educating the public about food waste	i DP5.E8 Food pricing	i DP5.S2 Using leftovers ii DP5.S3 Menu Planning iii DP5.S4 Daily versus weekly food needs	N/A	i DP5.L9 Food Product quality	i DP5.ENV5 Product knowledge

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Table 2
Key food production and consumption factors in Qatar.

ID	Factor	Explanation
F1	Food market competition	Consumer-friendly, competitive food market (an openly competitive market environment)
F2	Impact of Food Imports on Consumers	Individual and community's access to food based upon level of import controls (strict controls or not); market controls on how food is made available after being imported
F3	Standardised food regulations	Food regulations and food advise and its impact on consumer purchasing and consumption behaviours (Review date, international standards production date, best before only, storage);
F4	Education and training in retailers in food health and safety	Improving the training and development of food professionals in food safety
F5	Organising and planning food provision	Pre-planning of food supply chain requirements to satisfy supply
F6	Food quality management (producer, logistics, retailers)	Enforcing the implementation food standards within the food supply chain
F7	Improving the recycling of food & packaging	Uptake of food and associated waste item recycling
F8	Easy, open, low cost food market entry (Easiness of Market Access)	Access for food producers and consumers to food markets (this was combined with "Combined with Easiness of Market access factor")
F9	Bureaucracy in food authority	Level of bureaucracy (approval levels etc)
F10	Investment in Food Security	Level of investment in food security policy, organisation, strategy and implementation (production plant machinery, transportation, ICT, human resources, warehousing etc)
F11	Incentives to buy local produce	Promoting and developing local food organisations (farms, producers, SMEs)
F12	Working with local charities	Organising and planning the transfer of unused or wasted food to charity organisations
F13	Food safety through traceability	Improving the traceability of food items for increased food safety
F14	One unified food authority	Single organisation for food regulation and control standards
F15	Time to market	Time taken from food production through suppliers to consumers
F16	Safe and certified food	Organisation's ability to produce and provide consumers with safe and good quality food products in compliance with food regulations
F17	Collaboration between food authorities, suppliers and retailers	Collaboration between food authorities, suppliers and retailers
F18	Best practice food waste reduction	Sharing best practices to reduce food waste
F19	Human and Organisational Risks	Identifying risks relating to food safety
F20	Food waste	The level of food waste

food supply chain perspective). In addition, when assessing each causal relationship, the researchers were purely identifying causes and effects (and vice versa) rather than assuming *good* or *bad* outcomes from each relationship. This sought to reduce bias within the research design. Where possible the researchers sought to also identify and remove duplicate or similar entries (reduced list of factors from 33 to 20, i.e. a reduction of 39.39%).

STEP 2. The individual pairwise comparisons were then transposed into a single pairwise comparison matrix based upon common (similar) entries – regardless of the number of agreed shared weights.

STEP 3. Based upon a common agreement of causal weights across the 20 factors, the researchers then assigned a relative granular weighting that was indicative of the strength associated with the intensity of each pairwise comparison. For example, if the pairwise relationship F1–F5 is identified as a negative, "–", then the option is to weight this as "Very Low", "Low", "Medium", "High", "Very High" for each positive or negative causal relationship. This level of granularity sought to act as a strength indicator.

STEP 4. The individual relative granular weights were then consolidated into a single representation of causal interrelationships. This was achieved through evaluating each pair of granular weights, and where there was disagreement in across the range of weights, the researchers discussed and came to an agreed set of values. This process was carried out on a pairwise, factor-by-factor basis. The rules for moderation of these values are given in Table 3, with the agreed weight matrix in fuzzy values shown in Table 4.

Table 3
Moderation rules.

From Value	To Value	Moderated Value
VH	VL	M
VH	H	VH
VH	L	H
M	VL	L
M	VH	H
M	L	L
M	H	H
VL	L	VL
VL	H	L
VL	M	L
H	L	M

STEP 5. To assign numerical (quantitative values) weights to each factor within the initial state vector, the researchers assigned qualitative values to discuss and reach agreement on the state of each factor, e.g. "Low", "Very High", etc. Following the assignment of a qualitative value for each factor, the relevant numerical weighting was assigned as shown in Table 5 (details relating to the process of assigning the weights presented in Table 5 is discussed in the next section).

Table 4
Consolidated weight matrix.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20
F1																				VH+
F2	L-					H+		L-	H+										H+	
F3	L-					H+									VL-	H+	H+			
F4						VL+	L+											VL+		
F5																				VL-
F6																				
F7																				VL-
F8	L+														L-					H+
F9								L-					H+							
F10								H+			H+				L-		L+			
F11	L+																			
F12							H+													
F13																				
F14			L+						H-						VL-					
F15																				VL+
F16							L+						H+							
F17						H+							VH+					L+		
F18							VL+													
F19						H+														
F20																				

Table 5
The state vector of the factors for simulation.

ID	Factor	Fuzzy value	Numerical value
F1	Food market competition	High	0.8
F2	Import Control	Very Low	0.4
F3	Standardised food regulations	High	0.4
F4	Education and training in retailers in food health and safety	Low	0.2
F5	Demand planning throughout the food supply chain	Very Low	0.6
F6	Food quality management (producer, logistics, retailers)	Low	0.4
F7	Improving the recycling of food / packaging	Very Low	0.4
F8	Easy, open, low cost food market entry (Easiness of Market Access)	Very Low	0.6
F9	Bureaucracy in food authority	Very High	0.8
F10	Investments in Food logistics infrastructure	Low	0.2
F11	Investment on local production	Low	0.4
F12	Linkage to charities	Low	0.2
F13	Food chain traceability	Very Low	0.4
F14	One unified food authority	Very Low	0.4
F15	Time to market	High	0.8
F16	Certification	High	0.6
F17	Collaboration between food authorities, suppliers and retailers	Medium	0.6
F18	Sharing best practices to reduce food waste	Low	0.4
F19	Risk based approach to food packaging, transportation and inspection	Low	0.4
F20	Food waste	Medium	0.6

8. Fuzzy cognitive map simulation results, analysis and implications

To analyse the interrelationships between the 20 factors arising from the PESTLE prioritisation carried out across the three producers and five consumer participant groups, the researchers embarked upon using the FCM technique to identify those organisational relationships. The simulation analysis was conducted using PolicyCompass (http://alpha.policycompass.eu) a policy modelling and simulation tool developed by PolicyCompass, an EU funded research project. The simulation analysis can be done via other FCM simulation tools but the simulation results will not be sensitive to the selection of the tool. PolicyCompass was selected as it provides user-friendly graphic user interface and the simulation engine is based on well-known open source code JFCM (Java FCM, http://jfcm.megadix.it). The tool is available free in the public domain. There are of course other simulation tools available in the public domain.

FCM simulation is conducted using weight matrix (W) and factor vector (C). A weight w_{ij} describes the strength of causality between two factors. Weights should take values in the interval $[-1, 1]$ and the sign of the weighting indicates positive causality if $w_{ij} > 0$, which means that an increase of the value of factor C_i will cause an increase in the value of factor C_j. Obviously, a negative value of w_{ij} indicates the negative causality. When there is no relationship between factors, then $w_{ij} = 0$. The value of factor usually 'fuzzyfied' by mapping the real value and fizzyfied value in the interval [0, 1]. According to the scale of the fuzzyfication scheme, every value of factor fuzzyfied is given a fuzzy value – where levels of granularity for each weighting and the inferred context are assigned accordingly. Generally, the value of each factor(s) at time t is calculated by applying the calculation rule of equation below, computing the influence of other factors to the target factor:

$$x_i(t) = f\left(\sum_{j=1,\ j\neq i}^{n} x_j(t-1)w_{ji}\right) \tag{1}$$

where $x_i(t)$ is the value of factor C_i at time t, $x_j(t-1)$ is the value of factor C_j at time t-1, w_{ji} is the weight of the relationship between factor C_j and C_i and f is the activation function. At each time step, values of all factor in FCM change and recalculate according to this equation. We can also express the value of factors in FCM at time t as a matrix form. Assuming that vector $\mathbf{X}(t)$ is the n by 1 vector which gathers the value of n factors, and the matrix $\mathbf{W}$ is n by n

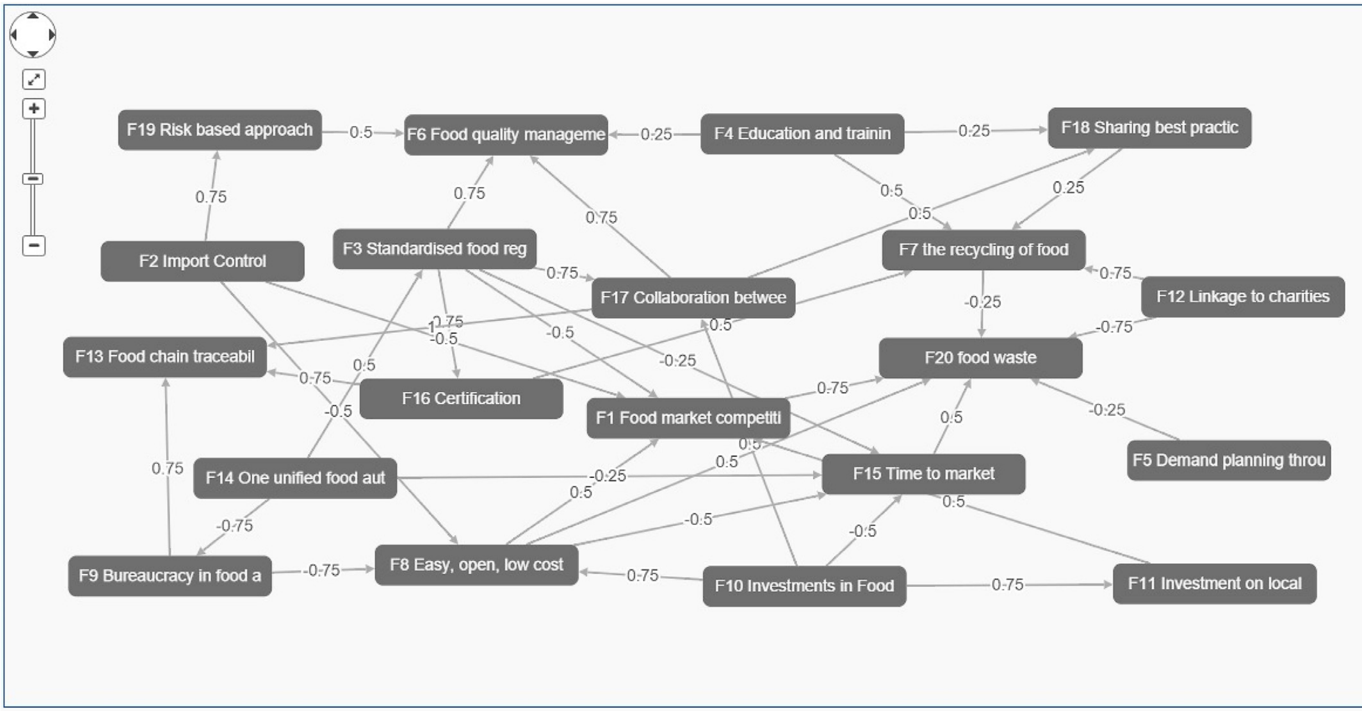

Fig. 2. FCM diagram in PolicyCompass.

matrix representing weights between n factors,

$$\boldsymbol{X}(t) = f\left(\boldsymbol{W}^T\boldsymbol{X}(t-1)\right) \tag{2}$$

The concept of activation function was borrowed from artificial neural networks. It is essentially a function that calculates the output of a factor based on its inputs, usually on the total sum. The output of activation function has its upper / under bound as +1 / −1. The most common type of activation function of an FCM is the sigmoid function that is a reciprocal of negative natural logarithms with some parameters. In addition to this function, tangent hyperbola and linear type activation functions have been used allow for contexts to be accommodated. The details of the activation functions provided by the platform are summarized below. Based on the definition of the equation and activation function, the authors can calculate the state vector X(t), which contains the values of all factors at time t. In the simulation of FCM, the calculation of the state vector will be iterated until the X(t) reaches the steady state that means no changes in the state vector after iterations.

Fig. 2 shows the FCM diagram based on weight matrix in Table 5. From the FCM, the authors have identified six factors which encompasses several organisational elements. These are import control (F2), education and training (F4), demand planning throughout the food supply chain (F5), investment in food logistics infrastructure (F10), linkage to charities (F12) and one unified food authority (Katajajuuri et al., June 2014)). These factors are not influenced by other factors but have an influence on other factors (i.e. have no incoming relationships from other nodes in the FCM). The initial vector for these six factors were set as 0.4 (low), 0.2 (very low), 0.6 (medium), 0.2 (very low), 0.2 (very low), and 0.4 (low) and the resulting simulation outcome is as shown in Fig. 3. As such the six factors that are unchanged have not been plotted in this figure (i.e. F2, F4, F5, F10, F12 and F14).

As shown in Fig. 3, the state vector of the system reaches a stable state after three iterations and the initial six factors make impacts to following nodes:

- Causal increases:
  - F3 – Standardised food regulations (0.400 ➔ 0.550, i.e. low ➔ medium)
  - F6 – Food quality management (0.400 ➔ 0.550, i.e. low ➔ high)
  - F7 – Improving the recycling of food (0.400 ➔ 0.770, i.e. low ➔ medium)
  - F11 – Incentives to buy local produce (0.400 ➔ 0.540, i.e. low ➔ medium)
  - F13 – Food chain traceability (0.400 ➔ 0.800, i.e. low ➔ high)
  - F18 – Sharing best practices to reduce food waste (0.400 ➔ 0.590, i.e. low ➔ medium)
  - F19 – Risk based approach to food process (0.400 ➔ 0.570, i.e. low ➔ medium)
- Causal decreases:
  - F1 – Food market competition (0.800 ➔ 0.500, i.e. high ➔ medium)
  - F8 – Easy open low-cost food market entry (0.600 ➔ 0.410, i.e. medium ➔ low)
  - F9 – Bureaucracy in food authority (0.800 ➔ 0.370, i.e. high ➔ low)
  - F15 – Time to market (0.800 ➔ 0.370, i.e. high ➔ low)

Thus, human and organisational initiatives to make improvements across the food supply chain (causal increases), tend to mitigate how food might be provided to consumers (causal decreases) – although this is with a reduction in bureaucracy which was highlighted as a common factor by workshop participants.

This is also noting that Incentives on local production (F11), Certification (F16) and food waste (F20) are not changed. Hence while decision makers can expect improvement on some indicators including food quality management (F6), bureaucracy in food authority (F9) and food chain traceability (F13) in the long term without any actions they are not able to expect improvement in food waste reduction (F20) reduction overall – and there is no significant causal decrease.

Decision makers may therefore need to take other actions to reduce food waste, and in this sense the researchers have identified six factors which might be manipulated to change address and

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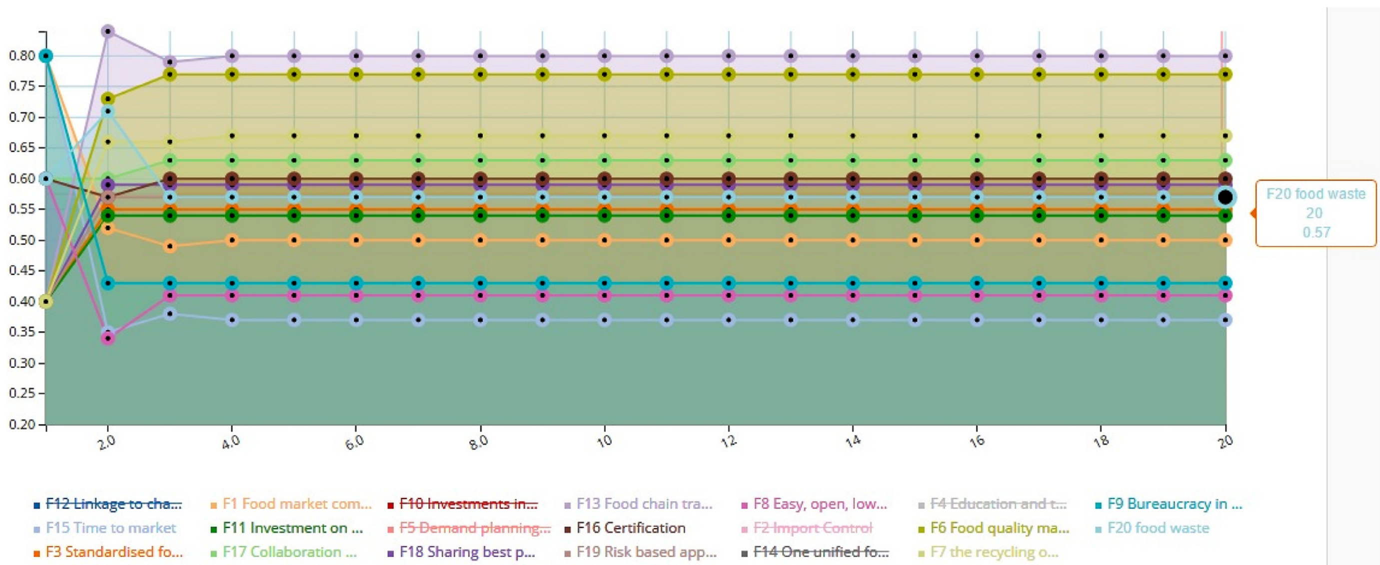

Fig. 3. Simulation result – scenario 1.

improve food waste reduction outcomes. This leads to a scenario where to increase food market competition (which showed signs of a causal decrease in the initial state of the FCM), a slight increase in import controls could be instigated (F2, low ➔ medium). Further, by dramatically improving education and training to retailers in food health and safety to learn and share best practice (F4, low ➔ high) as well as strengthening the linkage to charities to reuse and make use of food that is wasted (F12, very low ➔ very high) could also add to this stimulus. Conducting an organisational restructuring of food regulators into a single food authority (F13, low ➔ medium) alongside the above, may also improve the sharing best practice on food waste reduction (F18). Having more direct links to charities (F12) – which was not a requisite factor in the initial state of the FCM – also supports improvements in the recycling of food and packaging (F7) and has a direct impact on the reduction of food waste (F20). If we now assume a binding factor of having one unified food authority (F14), we can see the impact that this has in terms of multiple associations to other food waste factors in the FCM in Fig. 2, by following the inflows and outflows from node F14. These identify several policy-making routes to reducing food waste (F20) within the FCM as follows:

- One unified food authority (F14) ➔ time to market (F15) ➔ food waste (F20);
- One unified food authority (F14) ➔ standardised food regulation (F3) ➔ food market competition (F1) ➔ food waste (F20);
- One unified food authority (F14) ➔ standardised food regulation (F3) ➔ collaboration between food authorities, retailers and suppliers (F17) ➔ sharing best practices among stakeholders (F18) ➔ the recycling of food (F7) ➔ food waste (F20);
- One unified food authority (F14) ➔ bureaucracy in food authority (F9) ➔ easy, open, low cost market entry (F8) ➔ time to market (F15) ➔ food waste (F20);
- One unified food authority (F14) ➔ bureaucracy in food authority (F9) ➔ easy, open, low cost market entry (F8) ➔ food market competition (F1) ➔ food waste (F20).

This highlights that common routes to reducing food waste (F20) might typically be found through decision and policy making routes which relate to increased food market competition (F1); standardised food regulations (F3); easy, open, low cost food market entry (easiness of market access) (F8); some level of bureaucracy / control in a single food authority (F9); and effective time to market (F15) for food products.

To explore, a corresponding simulation scenario is applied and carried out, with the results shown in Fig. 4. In this case, again the state vector reached a steady state after 3 iterations. The results show that the change on four factors will reduce the food waste level (F20) from medium to low (0.6 ➔ 0.41). Particularly, the factors that directly affect food waste were affected by the changes: food market competition (F1, high ➔ low); time to market (F15, high ➔ low); the recycling of food (F7, low ➔ high); and bureaucracy in food authority (F9, high ➔ low).

Accordingly, the related causal impacts are:

- Causal increases:
  - F2 – Impact of food imports upon customers (0.500 ➔ 0.570, i.e. low ➔ medium)
- Causal decreases:
  - F1 – Food market competition (0.800 ➔ 0.600, i.e. high ➔ medium)
  - F3 – Standardised food regulations (0.460 ➔ 0.400, i.e. medium ➔ low)
  - F4 – Education and training in retailers in food health and safety, F5 – Organising and planning food provision, F6 – Food quality management (producer, logistics, retailers), F7 – Improving the recycling of food & packaging, F8 – Easy, open, low cost food market entry (Easiness of Market Access), F9 – Bureaucracy in food authority, F10 – Investment in Food Security, F11 – Incentives to buy local produce, F12 – Working with local charities, F13 – Food safety through traceability, F14 – One unified food authority, F15 – Time to market, F16 – Safe and certified food, F17 – Collaboration between food authorities, suppliers and retailers, F18 – Best practice food waste reduction, F19 – Human and Organisational Risks, F20 – Food waste: (0.470 ➔ 0.410, i.e. medium ➔ low)

This highlights that continuing with food imports has a potentially context-wide negative causal impact on all other factors. Further, Fig. 5 shows the corresponding L2 maximum error norm between the initial state of the FCM and the given scenario in Fig. 5, computed via the transfer function:

$$tanh\left(\frac{||\ u_a(i) - u_c\ (i)||}{||u_c\ (i)||}\right) \tag{3}$$

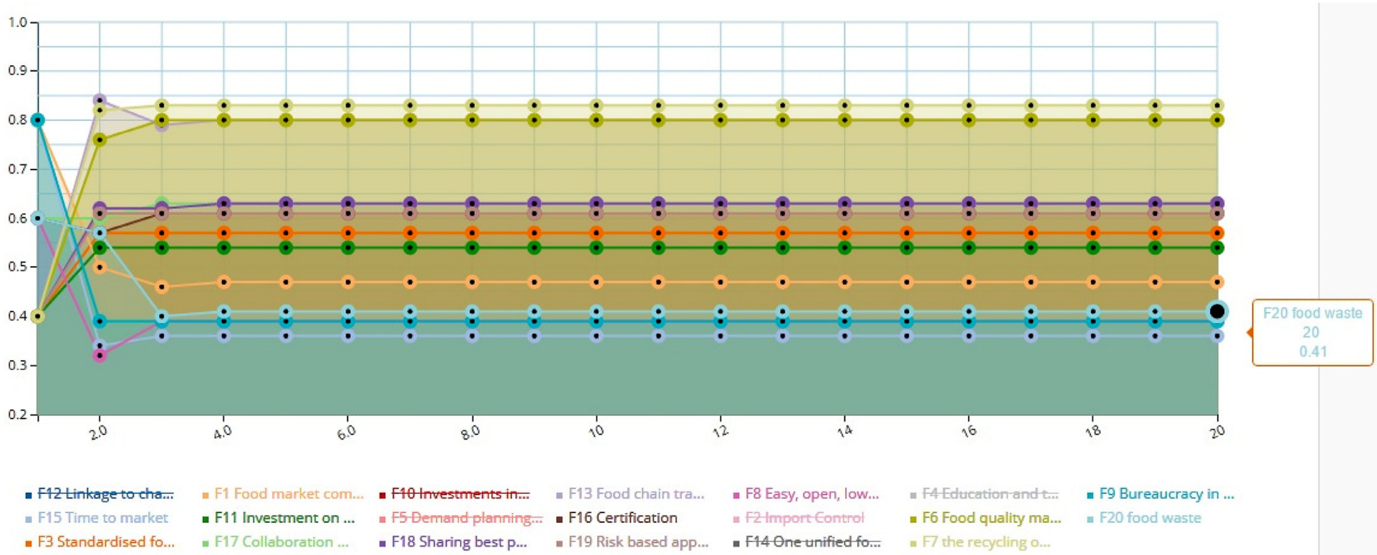

Fig. 4. FCM results for the given scenario.

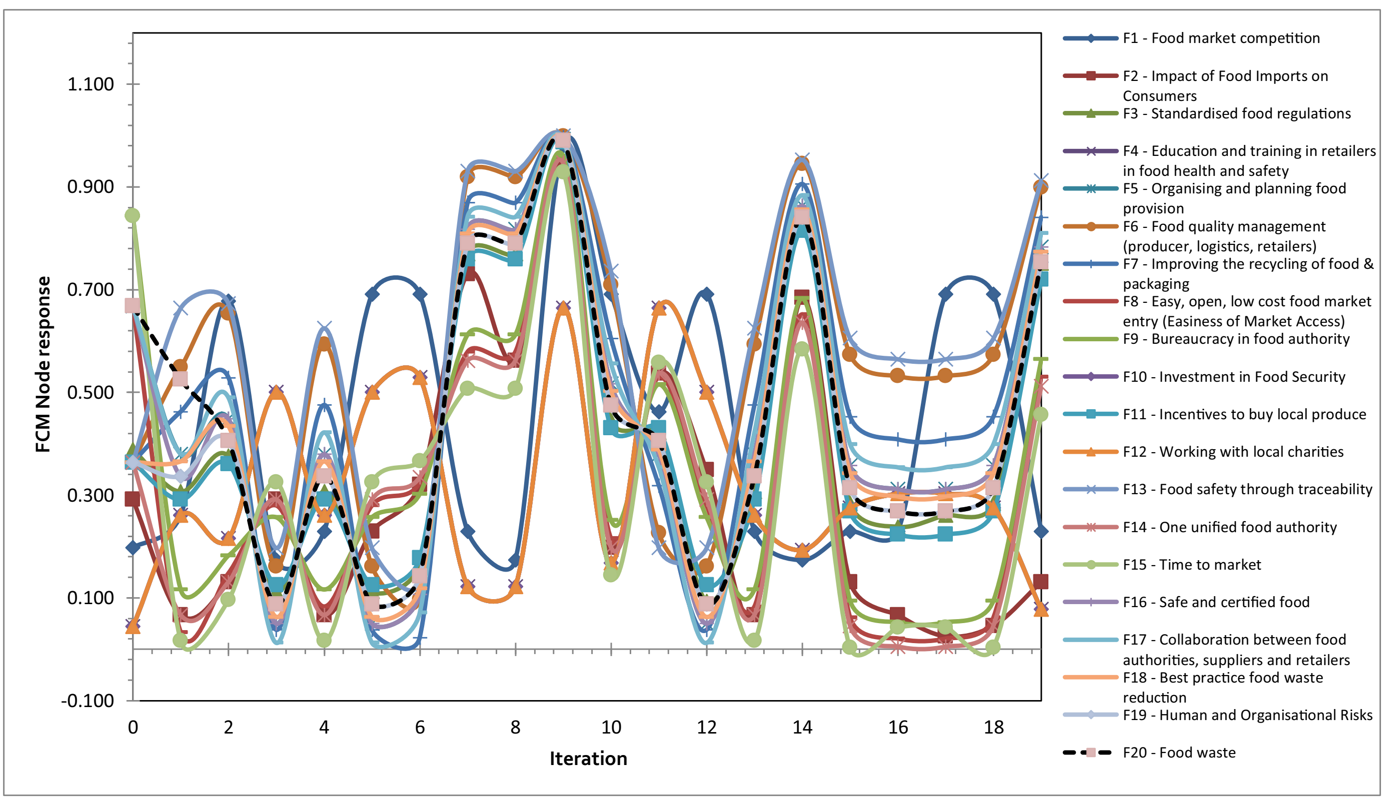

Fig. 5. FCM results – L2 Maximum Error Norm.

where u_a is the actual (initial) value and u_c is the computed (final) value for each ith iteration value of the FCM.

This shows further interesting detail in terms of interrelationships between factors relating to reducing food waste (F20). There is a cyclic dependency and parallel causal response between food market competition (F1) and working with local charities (F12) whose responses are somewhat in phase with each other after iteration 4. Subsequently there is a bunching of causal responses in an opposite causal sense from all other factors (F2-F11, and F13-F20 inclusive) from iteration 7.

Thus, when factors F1 and F12 have a positive causal response, F20 has a negative causal response and vice versa. Food waste (F20) is subsequently low when there is increasing (positive, rising) causal response to market competition (F1) and local charities involvement (F12).

This suggests that decisions that increase and open and provide access to a wider set of non-production and non-supply organisations and social groups may have a positive effect on reducing food waste in Qatar.

9. Recommendations and implications

9.1. Engineering management implication

The approach taken to explore and identify those pertinent organisational factors impinging upon the management of food waste, has practical managerial value for both up-and-down stream within a food security context. The involvement of groups of stakeholders from across agriculture, processing, packaging, distribution, retail, consumption, government and NGO spheres has sought to identify organizational factors that are inherent within the engineering management of business processes at different phases in the food waste chain. Our research has presented an applied research design which has engaged and included such stakeholders, directly utilising their expertise and business process knowledge to inform and define the boundaries of the food security and food waste problem space in a reflexive manner (Smith, 2008, Bourlakis et al., 2014). The structure of the design science inspired research design allows engineering managers to easily translate this stakeholder engagement approach into their own contexts (as ongoing management practice), in a method like that of Thunhurst and Barker (Thunhurst and Barker, 1999) whilst also recognising deep rooted behavioural theories (Hull, 1943).

The researchers believe the approach taken therefore allows managers to frame what can be defined as the "*uncertainties pertaining to relations between decision events*" (Casciaro, 1998). In this case, providing both an engagement mechanism through participative involvement with stakeholders (i.e. a strategic workshop using a strategic management tool, PESTLE); as well as a visual tool for managers to use to frame complex interdependencies (i.e. the FCM). This means that food producers, retailers, consumers and policy makers, will be better able to understand and evaluate potential policy impacts of their decisions in the absence of detailed facts (Eagle and Pentland, 2006) and where there is a "mess" of complex, interrelated and unstructured factors to be arranged into a coherent and scientific form (Sharif and Irani, 2012). The results highlight that the reduction of food waste appears to be influenced by several drivers that can be grouped into the following themes:

- *People and social-level knowledge:* as identified from the results, improvements to a range of factors including the standardisation of food regulations, food quality, food recycling, incentives for local food production, food chain traceability, the sharing of best practice and risk assessment *all* appear to have a positive causal impact upon the reduction of food waste. Management and policy-making interventions could therefore help here, through providing a greater number of knowledge transfer interventions such as community-based forums to share knowledge about food production, waste management strategies and tools, and associated food supply innovations.
- *Accessible food market sector:* noting that there is a strong negative causation between the effect of food imports on all other factors explored in this research, decision and policymakers should seek to employ strategies to support the growth of internal food production and supply capacity and capability. This will require decisions relating to managing the potential increase of food market activity and competition, improvements to food regulations, market entry and access, the impact of a unified food authority – supported through a just-in-time philosophy.
- *Organisational involvement*: an inclusion of the wider food chain organisational ecosystem is suggested as supporting food waste reduction through the results identified – particularly when there are interventions to improve market access and the overall growth of the internal (i.e. non-import-led) food production and supply sector. In addition, when considering the parallel aim of reducing food waste, food supply / food waste management decisions need to also consider and include a wider set of tier players beyond production, supply and delivery. In this case, the greater involvement of local charities to aid with the disbursement of food destined for waste recycling / landfill needs further consideration and exploration. This may be in turn supported through improvements to education and training.

9.2. Methodological implications

The research presented in this paper has sought to provide a scientific approach in the development of a new management perspective on food waste production, using the Design Science paradigm as an underlying construct for the small data collection (i.e. Research Methodology; Objectives for Solution; Design and Development; Testing and Demonstration; and, Evaluation). In doing so, the authors have provided an insight to empirically grounded factors that highlight upstream and downstream perspectives and their interrelationships around organisational food waste production. This has been achieved through using design science principles that have been represented through causal factors that supported the construction of Fuzzy Cognitive Maps (FCM) generated though simulated causal outputs. This approach has been demonstrated as supporting policy makers in the development of food waste management policy models underpinned using causal models, which are a form of Soft Systems Methodology (SSM) (Sharif and Irani, 2016).

9.3. Big data implications – the big data challenge

To address the wider aspects of the food security challenge and to now produce more generalizable findings, the authors need to consider the non-contextual implications of food loss and food waste as part of food supply chain systems. Hence, we need to consider that the (relatively) "small" amount of data and information assembled in this article has "big data" needs and implications. Thus, suggesting the scaling-up of data to make systemic sense (and trend spotting) within the wider food security debate. As Biggs et al. (Biggs et al., 2015) note, the multi-opportunity and multi-stakeholder nature of such societal finite resource problems results in a complex set of dynamics encompassing for example, *aquaculture, agriculture, soil science, climate science, extraction economics, sustainable energy production and technologies, food production, food processing* and *food waste* itself. Allied to the above, the combined producer, market maker, logistics and consumption/consumer aspects add another layer of complexity and interdependence upon shared resources across social, economic and environmental impacts). Such challenges cannot be explored with the use of small-data beyond contextually driven motivation, thus, there is a pressing need to now develop a wide-scale, hence big data, framing of the research landscape in terms of capturing the intricacies of information flow. This is in terms of repeated observations over space and time (time series data) from different perspectives as Jacobs (Jacobs, 2009) notes; as well as addressing those elements of *volume, variety* and *velocity* (Chen et al., 2012, McAfee and Brynjolfsson, 2012) that help define the big data context.

Hence, utilising concepts emerging in terms of the "industrial internet", so-called Industry 4.0 (Herman et al., 2015, Lee et al., 2014) and noting the contingent emerging aspects relating to viewing food security as a big data challenge (Tsiolias et al., August 2015, World Bank 28th October 2016) as well as the identified interrelationships presented in this research, the authors now propose a framework in Fig. 6 that will allow for the extrapolation

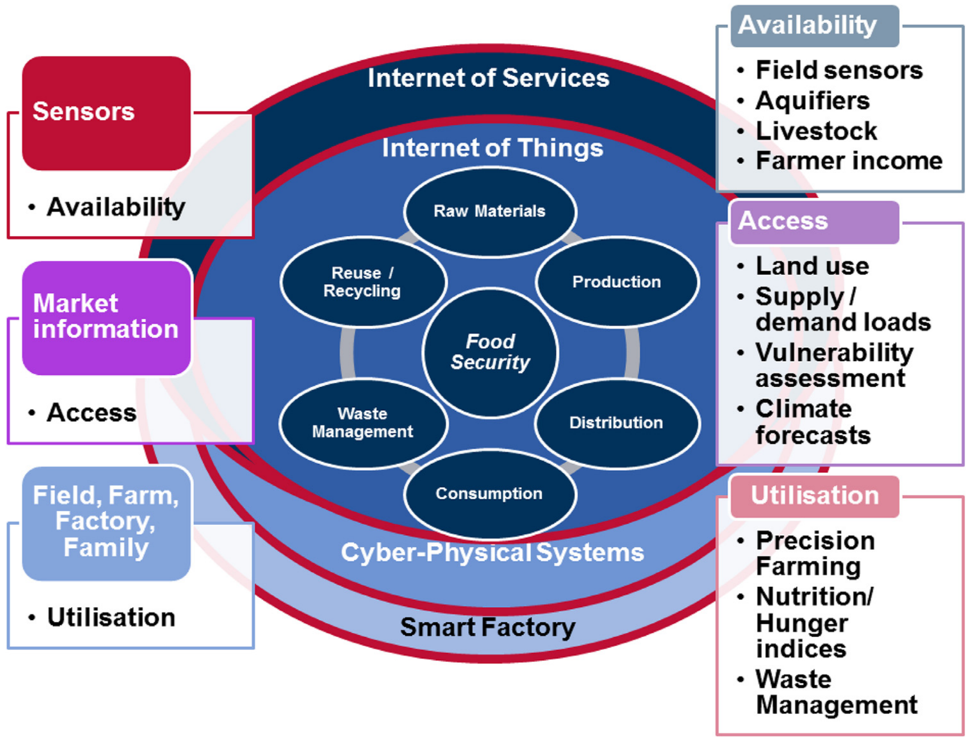

Fig. 6. Big data framework for food security.

Table 6
Alignment of food waste to Industry 4.0, big data and food security factors.

Big Data	Industry 4.0				Food Security
	IoT	*IoS*	*CPS*	*SF*	
Volume	Impact of food imports upon customers (F2)	One unified food authority (F14)	Market entry (F8)	Standardized food regulations (F3)	*Availability*
Variety		Food market competition (F1); Level of bureaucracy (F9)			*Access*
Velocity		Collaboration between food authorities and supply chain stakeholders (F17)	Time to market (F15); Working with local charities (F12)		*Utilisation*

and scalability of our findings to larger and more representative sample contexts thus leading to big data findings.

This framework seeks to identify *what* and *how* elements of the food security debate can be framed in the context of big data – further how these big data can be extracted and a resulting structure obtained to challenge and extend the research in this area.

As can be seen from the diagram, the core food supply chain lies at the heart of this framework – but includes and extends the supply chain in terms of a sustainable, circular economy context incorporating waste management and reuse / recycling elements (Ellen MacArthur Foundation January 2012, Jurgilevich et al., 2016, Linton et al., 2007). Noting the elements of new production and computer-oriented operations processes which are encapsulated within Internet 4.0 (i.e. Internet of Things, IoT; Internet of Services, IoS; Cyber-Physical Systems, CPS; and Smart Factories, SF) we further propose that food security elements of *Availability, Access* and *Utilisation* (on the left-hand side of this diagram) can be aligned with big data elements (on the right-hand side of the diagram). In addition, the specific aspects of food waste as identified from our research in this article can then be placed within a morphological grid and mapped to each of framework aspects as shown in Table 6.

9.4. Big data collection for use in the food security context

Noting the above, the authors wish to identify that big data needs to be captured across the food chain to make sense of the impact on food security. The core data may be in terms of field sensor, machinery and soil/livestock data; weather pattern, irrigation and precipitation data within the water chain; and energy supply/demand loads, consumption patterns, forecast planning and extraction / regeneration cycles within the energy chain. Whilst it is true that the data can be captured from these and many other sources, one key factor in big data strategies and data analytics is in the stratification and identification of types of data; and the resulting strategy for using big data and deriving value from it (Gandomi and Haider, 2015).

As both Marr (Marr, 2015) and Meer (Meer, 28th October 2016) highlight, the type and form of collection of data within a wider big data approach is heavily reliant upon the context of the situation. This then also should be aligned with a strategic or rather objective-based perspective, in terms of measurement or experimentation / exploration (Parise and Iyer, July / August 2012). As a result, and within the context of this research, three fundamental types of food security data may then be considered, which can then be mapped against dimensions of data capture and a resulting objective, as shown in Table 7.

Table 7
Big Data capture options for Food Security applications (adapted from Marr, 2015; Meer, 2013 ; Parise et al., 2012 and Tsai et al., 2016).

Data Type	Big Data capture mechanism	Example Big Data source	Big Data Analytics approach	Big Data Objective
Structured	• Transactional (through business process / chain interactions)	Food supply chain, Economic and Market data	Classification	Measurement
Semi-Structured	• Compiled (from existing databases and datasets)	3PL companies, Government Organisations, Regulators, Climate forecasts, Vulnerability analyses	Sequential Patterns Association Rules	
Unstructured	• Experimental (from food security strategy and policy models) • Captured (from sensors) • User generated (from consumers or those affected by food security directly)	Field sensor data Weather reports, Consumer demand, Health / Nutrition indices	Clustering / Data Mining Predictive analytics	Experimentation

This table therefore highlights the extent to which big data manifests itself within the food security context and the potential sources of data and where they may be captured. Future research to extend and challenge these notions would therefore seek to balance all of these elements in order to then allow for a range of food security scenarios / perspectives to be developed and assessed using big data analytics techniques as shown also (Tsai et al., 2015).

10. Conclusions

Concerns around food security are driving debate around production efficiency and the sustainability of food chains. Increased demand for physical resources like arable land for crop production or grazing of livestock through to lakes and seas for fisheries, are equally set to raise concerns around food security. Such considerations are prompting a rethink around food waste, (given the growth of new resources are reaching a plateau) which is increasingly seen as a lost resource, specifically around *where* and *how* it occurs throughout food chains.

This paper has proposed a way to explore a set of organizational factors that contribute to food security management through waste reduction and has identified causal relationships between organizational factors using the FCM technique. Both the factors and their interrelationships are identified through a qualitative data elicitation process. This research has therefore sought to provide those with management decision-making responsibility with a means by which a range of strategic options and opportunities can be evaluated, whilst also offering a practical basis through which resilience can be engineered in to food chains (being based on science, practical and experiential input rather than intuition.

The authors have shown that a range of recurrent organizational factors may have an impact on reducing food waste in a causal sense, including: food market competition (F1); impact of food imports upon customers (F2); standardized food regulations (F3); easy, open, low cost food market entry (easiness of market access) (F8); level of bureaucracy (F9); working with local charities (F12); one unified food authority (F14); time to market (F15); collaboration between food authorities and supply chain stakeholders (F17).

The simulation results generated have been clear in representing how food waste changes as policy makers alter policies. The factors are key elements contributing to food waste thus offering themselves as enablers to promote food security. Although not shown as a visible positive or negative causal effect, the authors also believe that education and training of stakeholders in the food chain (F4) may inherently contribute towards the impact on the reduction of food waste (F20). In doing so, promoting an increase in the recycling of food waste (F7) and thus better food quality management.

The authors identified three key areas of managerial and practical implication because of the findings.

Noting the recurrent factors within the mapping of the workshop participant responses and the subsequent analysis via the FCM technique, the authors suggest that management interventions to manage and mitigate the effects of food security and food waste should include *knowledge transfer, market access* and *wider organisational involvement interventions*. This signifies a notable shift in approach to dealing with food security beyond purely a risk-driven issue alone; and hence highlights the importance of taking and including human ‘people’ and organisational factors as part of the solution (rather than as part of the problem) when framing a perspective on food security or waste reduction. Finally, while it was not the intention of this paper to make a theoretical contribution, the food security challenges explored in this paper does have the potential to evolve and contribute to a variety of conceptual frameworks and theoretical perspectives such as for example drive reduction theory developed by Hull (Hull, 1943), along with others in the policy, supply chain and consumer behaviour domains.

The methodological implications of the paper are also considered significant. The FCM approach provides policy makers with advantages in policy modelling and simulation via diagrammatic representation of policy variables. Given the FCM technique is a non-parametric method, it allows as many variables as necessary to be incorporated within the model for analysis. Therefore, the approach reported in this paper has an advantage over parametric methods that require data-based assumption (normal distribution). As a result, it is often difficult to have a *good level of fitness* of a model against a set of data if qualitative variables increase within the model. The FCM simulation also has allowed the researchers to use fuzzy casual, as opposed to precise or "crisp", relationships at it is considered difficult to collect accurate data in social systems when data are collected from human participants (Casciaro, 1998, Eagle and Pentland, 2006).

The stakeholder-centric design science research approach that acts as the conceptual basis of this research, provides a rigorous approach to engaging stakeholders across different organisations, which may be amenable and understandable in terms of shared engineering terminology by engineering managers. The authors believe that this research and its findings provide a framework for reflexive insight into the complex "mess" of managing food security and food waste. Hence, the results of this research are expected to provide a positive contribution to sustaining and potentially improving levels of food security.

10.1. Limitations and future avenues of research

The authors now wish to note some limitations of this research along with potential avenues for future work. Noting the design science approach taken to develop the FCM, the authors believe that further development is required of a more objective-centred, and flexibly-adaptable modelling artefact that can be used by team members and managers in managing food waste. In addition, whilst qualifying and quantifying the stakeholder responses, the researchers did not employ any additional techniques to reduce individual stakeholder subjective bias – further, the application of word-based (and subsequently, quantified) weightings and the resulting fuzzification was based upon prior experience and familiarity of applying this technique (Sharif and Irani, 2006, Sharif and Irani, 2012). It is also noted that both the factors and their interrelationships were identified through a subjective interpretive process, where inconsistences are likely to occur across data collection points but explained through the *rich* qualitative nature of the data collection process. Although the data collection points were narrow in focus and limited in number, this limitation need to be considered in respect of the size of the State of Qatar and *relative* simplicity of their food supply chain.

Also, this paper has presented the results of a limited number of scenarios – additional examples and contexts to explore additional facets of food waste and food security would extend this work and bring include additional voices and narratives to the overall research (such as delineating specific stakeholder groups, i.e. food producers, food suppliers, food retailers, food waste managers, policy makers and related interest groups). The researchers also wish to note that the present research and simulation results require further validation and feedback from stakeholders. This may be achieved via the well-known Delphi method to harvest expert opinion in a more structured manner involving a wider set of participants to ensure that the food waste perspectives being traversed can be verified for accuracy and relevancy (as well as being validated). The current article has also not sought to unpack food waste at a granular level or indeed from an embodied energy perspective, which is equally significant and worthy of further research. The authors believe that this research will be of interest to other geographical territories that share similar characteristics to those of the State of Qatar as it may provide thoughtful insights to how resilience in the food security supply chain can be embedded. Finally, the authors also suggest that an extension of the study to other food waste contexts within the Gulf region or indeed Europe and / or the United States would be useful to compare, contrast and generalise wider human and organisational food security behaviours as identified in the policy domain (Sharif and Irani, 2016).

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